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ABSTRACT

The paper reports results and discusses implications of three studies on captioning films and television programs for deaf audiences. Study I dealt with the short-term visual memory required in recognition of fingerspelled letters, while study II focused on serial position effects and forward making (interference produced by first stimulus on the second), and study III concerned the generalizeability of inferences from results with fingerspelling across systems of linguistic symbols. Implications of the research for short-term memory strategies and letter recognition are discussed in terms of individual differences in coding strategies, letter recognition and task demands, and the interaction of the task and individual differences in coding strategies. Practical implications for captioning are seen to cover future research study design and to indicate the possibility that because of differences in cognitive modes there is no one optimal means of captioning material for deaf students. (CL)

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FINAL REPORT

Standards for Captioning Film and Television Programs for Deaf Children

Project #H01165J

Bureau of Education for the Handicapped

U.S. Office of Education

Submitted by

Deafness Research & Training Center

New York University

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EC 120884

Standards for Captioning of Films and Television Programs for Deaf Children

Good captioning consists of the appropriate substitution of written words for the audio portion of films and television programs. If captions appropriate to the needs of deaf viewers can be produced, then the breadth and quality of training available to deaf students can be greatly increased. The initial objective of the present research was to produce a set of standards for the captioning of visual displays for deaf and hard of hearing children. It was reasoned that, with careful manipulation of such variables as the size, style, and placement of printed captions, guidelines could be established which would allow systematic adjustment of these physical parameters of captions to the ages and reading levels of groups of deaf and hard of hearing children.

Our original design was clearly a logical and practicable approach to the problem, given the practices followed by television stations in captioning network programs (Freebairn, Stewart, Delk, & Gentile, 1976). However, our first controlled studies indicated that many current practices in captioning may be based on unfounded assumptions. Indeed, we believe that the most important results of the series of studies reported herein are a critical redefinition and an elaboration of the problems which necessarily will be encountered in producing optimally captioned instructional programs to deaf children.

From the results of our study, it would appear that, more important than the main effects of the more obvious factors, of size, style, and placement of captions, is the interaction of the physical characteristics of captions with the cognitive attributes of the group which will be viewing the captioned material. Indeed, our initial results were so striking that it became clear that an interaction between certain cognitive characteristics of our subjects and the nature of the captions had to be studied before useable statements as to how to optimize captions for deaf audiences could be made.

As a result of our pursuit of this line of research, we think that we may have uncovered a consistent difference among groups of deaf viewers in their styles of processing visual linguistic material. This difference is important in that the mode of visual processing which characterizes a particular deaf audience may turn out to be the critical determinant of which captioning style will be effective for them. Moreover, we hope that further research will develop tests which are practicably administered outside of the laboratory setting and which will allow ready evaluation of the cognitive characteristics of a group of deaf students for whom the production of a particular set of captions is targeted.

In the following report, we will first outline those preliminary results of our study which necessitated a redefinition of the problem of establishing standards for the production of captioned material for

deaf audiences. Then we will detail the experiments undertaken to pursue the implications of our initial findings.

Preliminary Studies: Stimulus versus Individual Engendered Variation

The original design of our study specified that the primary dependent measure would be error rates in response to captioned stimuli which were to vary in complexity as well as in style and locus of font. Additionally, it was planned that reaction time (RT) data would be collected from a smaller number of subjects as a secondary dependent measure. The original purpose of the RT study was to help validate an interpretation of differences in error rates as being due to differential requirements of time, rather than being an artifact of an interaction of experimental material and reading ability.

These two complementary approaches to the problem of establishing guidelines for captioning involved tasks which, like televised captions, would require that subjects process linguistic data which was visually displayed. Moreover, unlike the situation in which a deaf person is reading a book, various physical parameters of these visual displays, such as temporal duration, distance, and size, would be only partially under the control of the viewer.

The first step in carrying out such a study was to design the experimental material so as to minimize the possibility that any obtained differences in caption legibility might be an artifact of the specific procedures employed in the laboratory setting. In anticipation of these problems, pilot research on deaf subjects' performance on an analogous task, the short-term recall of fingerspelled captions, had been undertaken. In the results of these studies, some physical parameters, such as angle of regard, seemed to be unimportant in their effect on deaf subjects' recognition and recall of fingerspelled letters within a sequence, while others--length of sequence, for example, as well as the serial position and the interval separating letters within a sequence--had shown marked effects. Briefly, it had been found that for bursts of three fingerspelled letters, recall was high over all three serial positions. In contrast, with strings of six letters, performance tended to show a monotone decrement with serial position, with a slight improvement in recall for the last presented letter. These serial position effects, however, seemed to be sensitive to the temporal interval between the letters within a string.

The important point is that, while the results of these pilot studies had attained an acceptable level of significance, there seemed to have been considerably greater individual variability in the results than would have been expected, given the nature of the manipulations performed. Thus, much individual variability had been observed in basic data on performance in a visual task which could be considered cognitively analogous to processing printed captions on television. Unless the source of this variability in the recall of fingerspelled letters could

be identified and controlled, standards resulting from our study of printed captions might be contaminated by a great deal of individual or experimental error of unidentified origin.

The most efficient strategy for isolating possible sources of internal and external invalidity in our captioning study was to start with fingerspelling recognition, since it was a relatively well-studied but cognitively analogous experimental task. The fingerspelling recognition task was deemed analogous, first, in that linguistic material was presented by means of a visual medium (television), in combination with a nonlinguistic visual display (the fingerspeller). Addition, more fundamental, similarities in the processing of the two types of captions will be discussed in the concluding section of this paper. It was decided, therefore, to first validate the differences obtained on the fingerspelling task and to more clearly differentiate that variation in performance due to the deliberate experimental manipulation of stimuli from variation due to the interaction of stimulus parameters with as yet undefined differences in individual subjects' processing of the stimulus material.

Experiment 1

With hearing subjects, serially presented items seem to be retained with different efficiency depending upon the modality of presentation (Penney, 1975). While no consistent serial position effect seems to have been found for retention of strings of visual items, memory for auditory items presented serially seems regularly to produce bow-shaped curves in which items presented at the middle of the series are most poorly retained (Murdock, 1974). One would not necessarily expect that deaf subjects' sensitivity to variations in the temporal distributions of visual-linguistic symbols would follow a pattern similar to that of hearing subjects, however. This is because for hearing subjects, in contrast to deaf people, spoken language has a fixed temporal sequence of utterances, while visually presented linguistic symbols, such as books and written captions, are typically static.

Results of studies in which visual material has been presented sequentially to deaf subjects have, in fact, been contradictory (Olsson & Furth, 1966; Segal & Fusella, 1970; Brooks, 1967, 1968). Reading fingerspelled captions, however, would seem to require the retention and integration of series of dynamic visual items over time, all of which precedes the subject's understanding of the cognitive message being conveyed via fingerspelling. Therefore, replicating our results as to how deaf subjects' memory for individual letters might vary with the length of the stimulus string, and with the position of each item within the string, was considered a natural starting point.

Method. The fingerspelled items were presented on videotape in bursts of three or six fingerspelled letters, selected randomly with the constraints that they would spell no words and that no letter would be repeated within a burst or within the preceding or following bursts. Each burst consisted of a start sign, the letters, and a finish sign. These were presented at a rate of 300 msec/letter, and averaged about 2.4 sec for a six letter burst. The intertrial interval was 20 sec. Eighty-one bursts of three letters each and 81 bursts of six letters

each were presented in groups of 27 bursts. The groups of bursts were randomized for each experimental session as to order of presentation. The first two bursts of each group were counted as practice trials. Subjects were instructed to write the letters they saw upon completion of each burst's presentation.

Each burst was preceded by a fadein to the image of the speller who remained on screen, still, for one to two seconds; each burst was followed by a one second pause after which the picture snapped off. The screen was blank during each response period. The speller sat at a 45° angle to the camera at all times. Letters were spelled with the right hand at an average rate of 300 milliseconds per letter.

Both the fingerspelled bursts and the instructions were videotaped. The tapes were shown on a 12-inch Sony monitor placed on a table against a dark green backdrop. Lights were partly dimmed. Subjects sat approximately 3½ meters from the monitor. Each session began with an instruction period lasting from 20 to 30 minutes and including practice trials. Instructions were signed and mouthed simultaneously. An interpreter was present at most instruction periods. Subjects were run singly or in pairs, separated from each other by a screen. Subjects were forced to make the appropriate number of responses, guessing if necessary, and were instructed not to respond until after the finish sign was made at the end of each burst.

The 11 naive subjects were deaf and ranged in age from 26 to 55, with a mean age of 44 years. Subjects' years of education ranged from 8 to 18, with 13 the mean. The last grade of schooling completed ranged from the 8th grade to 2 years of college.

Table 1

Mean Per Cent Correct Letter Report for the Three and Six Serial Positions of Experiment 1

	Serial Position					
	1	2	3	4	5	6
Three Letter Burst	93	90	86	--	--	--
Six Letter Burst	88	72	65	60	52	51

Results. The report for both three and six letter strings shows monotone performance decrements as a function of the serial position of the letters (Table 1). The difference in slope over the first three items was statistically significant, as shown by a repeated measures analysis of variance yielding an F (1,10) = 44.49, $p < .01$, for burst size, and a burst X serial position interaction term with an F (2,20) = 16.15, $p < .01$.

Discussion. It would appear that deaf subjects' recognition of fingerspelled letters might depend upon a special short-term visual memory which retains a sequential representation of the items for a long enough period for the subject to complete his recognition of each item. In this sequence, the first item presented is the first item identified, and so forth. It is the limited capacity of this short-term visual store, and the increased load placed on its capacity by an additional three letters, which account for the difference in slope between the three and six item serial position curves.

Two questions which can be raised, however, concern the generalizeability of inferences from these results to situations in which the experimental task requires that printed captions be read. First, are the variations in performance with serial position, obtained in Experiment 1, the result of a prerecognition interference of one letter with another, the source of which is the sequential nature of our stimulus presentation procedures? If not, then we might reasonably anticipate that the serial position effects obtained with fingerspelled letters may represent, at least in part, some kind of cognitive interference or selectivity which will also be operative in the processing of groups of simultaneously presented stimuli, like those employed in printed captions. The second question concerns the generalizeability of inferences from results with fingerspelling across sytems of linguistic symbols: is the obtained sensitivity of performance to serial position a manifestation of letter recognition processes associated only with fingerspelled but not with printed letters? Experiment 2 was designed in response to the first question, while Experiment 3 addresses itself in part to the second.

Experiment 2

The serial position effects obtained in Experiment 1 were tentatively explained as resulting from a short-term visual store characterized by a limited capacity and an essentially sequential mode of processing. Although similar explanations have been offered for somewhat different visual phenomena (Sperling, 1967), there are other explanations which would apply equally well to the data presented in Table 1. The declining monotone functions associated with serial position are like those found in some visual masking studies (Kahneman, 1968; Lefton, 1972; Weisstein, 1968). Masking refers to a decline in the recognition of one of two stimuli presented closely in time. If recognition of the preceding stimulus interferes with the perception of the following stimulus, the first stimulus is said to mask the second stimulus. Because the interference is produced by the leading stimulus, this masking effect is referred to as forward masking, and the functions presented in Table 1 might represent just such a forward masking effect.

In order to ensure that these functions did not represent interference due to forward masking, the intelligibility of particular letters within six letter sequences was examined. The observer's task, in this study, was to detect a critical letter rather than to report all letters present. Under these conditions, the absence of a monotonic decline in accuracy of report with serial position would indicate that visual masking was not responsible for the monotone decline in the serial position curves of Experiment 1.

Method. Two hundred and forty bursts of six letters each were presented in 8 blocks of 30 bursts each. The 8 blocks were randomized as to order of presentation. Four target letters, R, X, S, and C were selected randomly from the fingerspelling alphabet divided into three categories of manual configuration: a) projecting fingers; b) closed hand; c) open hand. Each target letter occurred 120 times in the 240 bursts, 20 times in each serial position but no more than once in a burst. Each burst was preceded by a start sign and followed by a finish sign. The intertrial interval was 15 sec. Presentation rate was 300 msec/letter.

Each subject was randomly assigned a target letter. Subjects wrote a plus if they saw the letter, a zero if they did not. Subjects were run singly. With these exceptions, procedure was the same as in Experiment 1.

Of the 8 subjects, 6 had been in the previous fingerspelling study, 2 were naive. Their ages ranged from 30 to 77 with a mean age of 46. Years of education ranged from 7 to 21; mean years of education was 14. The last year of schooling completed ranged from 7th grade to college graduate.

Results and discussion. Minimal interference effects are apparent in the data plotted in Table 2. Yet, in a masking situation, detection functions have the same form as recognition functions (Stewart & Purcell, 1974). Therefore, because these results are so unlike the results of Experiment 1, the monotone decreasing functions of that experiment do not seem attributable to forward masking interference to any significant degree.

Table 2

Mean Per Cent Correct Detection of Target Letter

Serial Position					
1	2	3	4	5	6
90	100	96	98	98	95

The results of Experiment 2 thus support the validity of an interpretation of our findings in Experiment 1 as being due to short-term memory processing rather than to a masking effect. This is especially reassuring in view of the attention recently given in the experimental literature to the possibility that the results of some letter recognition studies might actually have been artifacts of uncontrolled masking effects (Estes, 1975; Mason & Katz, 1976; Smith, 1976).

Styles of Processing Linguistic Material

The results of Experiment 2 suggested that, rather than being the manifestation of a masking interference effect specifically associated with sequential stimulus presentation, the serial position effects obtained in Experiment 1 could be attributed to the letter recognition process itself, and possibly to the limited capacity of a temporary store employed in the processing of visually presented letters. It seemed reasonable, therefore, to expect that the mechanism underlying the serial position effects observed with these sequentially presented stimuli might also determine the processing of groups of stimuli viewed under conditions of simultaneous presentation.

It now remained to examine the manner in which this mechanism generalized, not only to conditons of simultaneity similar to those employed with printed captions, but to the processing of another system of linguistic symbols, such as printed letters. As mentioned earlier, however, in pilot studies much like Experiment 1, while serial position effects on letter recognition were of substantial magnitude and had attained the desired level of significance, somewhat greater variability had been observed than might have been expected if serial position were the only important source of variation. Moreover, other pilot studies, in which the rate of presentation of fingerspelled letters had been manipulated, had indicated that there might be systematic individual variation in the manner in which the serial position of a fingerspelled letter's position within a string affected its recognition. If so, then these systematic individual differences might well be expected to carry over to the cognitive processing of printed captions, and it might therefore be essential that this source of variation be considered in any set of standards for the construction of captions useful to a wide variety of target audiences.

It may be helpful at this point to review some of the results obtained in pilot studies with manipulation of presentation speed. The serial position effects observed in Experiment 1 and explored in Experiment 2 were obtained with a presentation rate which was rapid, approximately 300 msec/letter, although within the range of normal fingerspelling speed. The observers we had tested to date, in these and in other fingerspelling experiments, generally showed a monotone and decreasing serial position curve for strings of rapidly spelled letters. At slower tempos, however, some observers showed bow-shaped serial position curves usually found in hearing subjects with short-term auditory memory. Other observers continued to show monotone decreasing serial position curves, although their overall performance increased with a decrease in tempo. Nothing from their history suggested that there should be these differences among deaf observers (Stewart & Hochberg, 1974).

One possibility presented itself, however. Those observers who generate bow-shaped serial position curves might rely on an auditory memory for retaining letters once they have succeeded in identifying them, or more correctly, in the case of deaf people, a memory which functions much like an auditory memory. Conrad (1972), based upon the fact that some deaf children confuse letters that are acoustically similar,

has made a comparable suggestion.

Experiment 3

In light of these speculations, we designed Experiment 3 with the aim of replicating the findings of those pilot experiments in which tempo was manipulated. The design of these earlier studies was refined, however, in order, first, to validate the nature of the observed differences in coding and, second, to enable examination of the way in which these differences, if replicated, might relate to differences in the processing of printed captions.

The first part of our experimental strategy consisted of dividing the subjects into two groups: those who, at slower tempos of fingerspelling, exhibited bow-shaped serial position curves, and those whose serial position curves were essentially monotone and decreasing even at these slower tempos. It was reasoned that, if the monotone declining function generally obtained with rapid fingerspelling was characteristic only of those observers with no auditory-like memory, the two groups in this experiment should exhibit different serial position curves in the rapid tempo condition. The curve for those with no auditory-like memory should be monotone and decreasing; the curve for those with an auditory-like memory should be nonmonotone with a pronounced improvement for the last two or three serial positions.

The second part of the strategy adopted in Experiment 3 was intended to provide an independent source of verification of the correctness of categorizing observers in one of these two groups, as well as to examine the possibility that related individual differences existed in the processing of printed letters. Accordingly, additional data were gathered on the subjects' relative ability to make physical as opposed to name matches of letters of the alphabet, a task which is thought to reflect the strategies involved in the processing and coding of visual information. Specifically, it is known that identifying physically similar letters of the alphabet, such as A A, takes less time than identifying the same letters when they are physically dissimilar, such as A a. The increase in identification time is thought to represent the time required by an observer to recode the visual stimuli into a cognitive representation (Posner, Boies, Eichelman, & Taylor, 1969). If it is this cognitive representation which functions like an auditory short-term memory and which, as a result, generates bow-shaped serial position curves, then those observers who show the longest reaction times to physically dissimilar but cognitively equivalent letters of the alphabet should be most likely to produce nonmonotone serial position curves.

For two additional reasons, the letter matching paradigm was considered particularly apt to the problems of interest in Experiment 3. The logic by which performance on the letter-matching task was seen to bear on the ease with which subjects would process printed captions is fairly straightforward. Performance on physical matches should relate directly to the legibility of captions, irrespective of their

cognitive complexity, while the ease with which captions, as linguistic material, are read may be reflected in their performance on the mixed-case, name, matches.

It will be recalled, moreover, that the original design of these studies called for the collection of data on RT to caption recognition as a procedure for validating inferences to be made from subjects' error rates under different conditions of caption presentation. If the individual differences in linguistic coding strategies now suspected to exist were substantiated, then the collection of baseline RT data on a somewhat simpler task would likely be indicated. Letter matching was just such a task, requiring as a major skill only the ability to recognize the upper and lower case letters of the printed alphabet. Reaction time to letter matching, therefore, would provide a baseline against which exposure times required for more complex materials could subsequently be assessed.

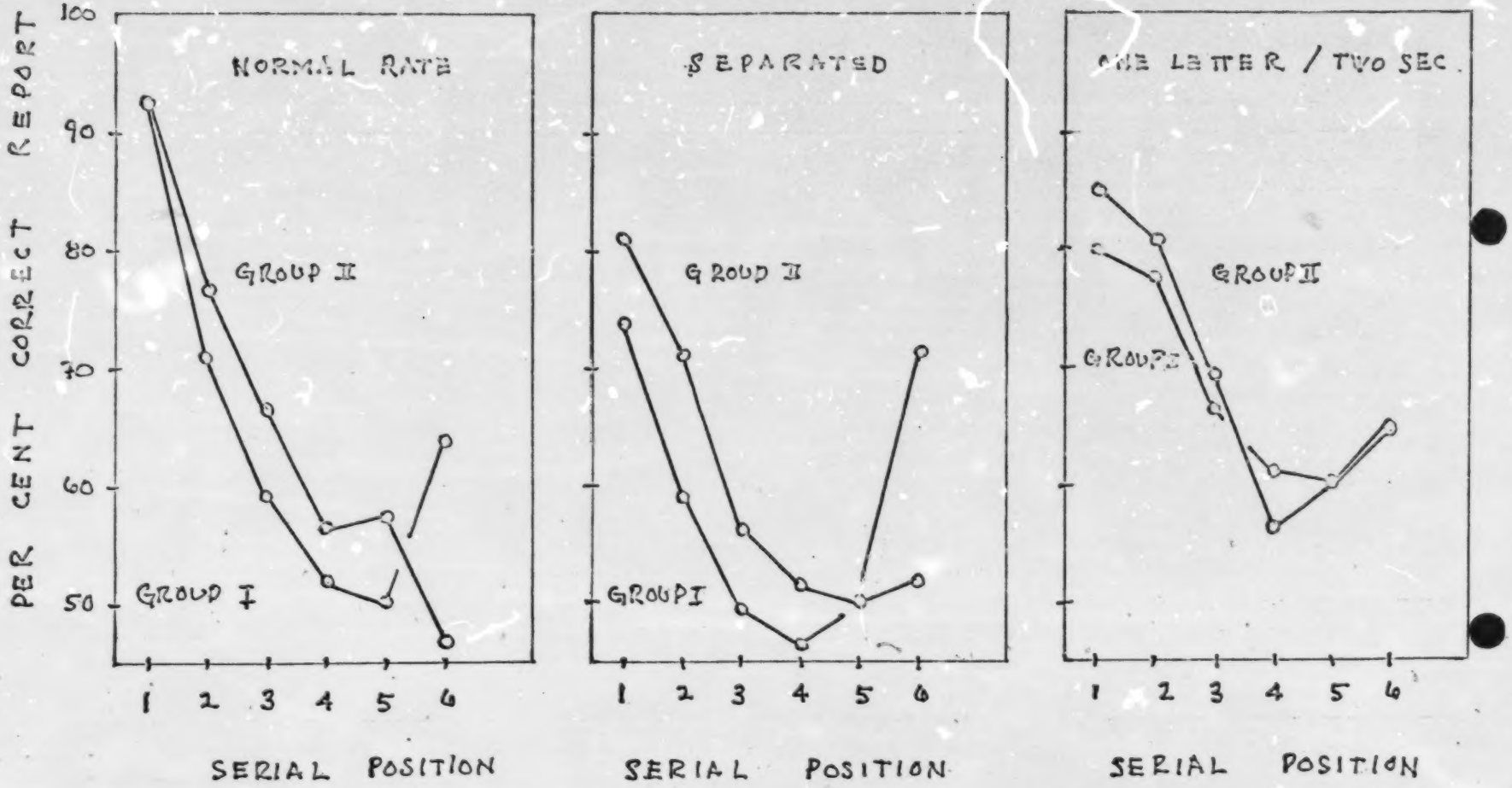
General method. Two separate sets of stimuli and two separate tasks were employed. Stimuli were photographic transparencies of printed letters in Part A, and videotapes of fingerspelled letters in Part B. Subjects completed the two tasks on two separate days; the order of the two sessions was random for each subject.

Method, part A. The printed letters A, B, F, H, and K, in upper and lower case were displayed as 35 mm transparencies, and appeared as white letters on a dark grey background. The letters were paired so that there were two ways in which they might match and two kinds of pairs in which the letters would not match. In a physical match, for example, A A , the two letters were nominally the same and were of the same case. In a name match, for example, A a , the two letters were nominally the same but of different case. In a physical mismatch, the letters were both nominally different and of different case; in a second type of mismatch, the letters were different but of the same case. The pairings were random with the constraint that there was an equal number of the four types of pairs.

After an hour of practice, 240 pairings of the letters were presented to the subjects, who indicated whether the letters were the same or different by means of a telegraph key. Subjects were run singly and were instructed to respond as accurately and as quickly as possible. Stimuli offset immediately upon the subject's response. The subjects' reaction time was recorded by means of an Iconix time base and latency buffer.

Method, part B. Fifty-four bursts of six fingerspelled letters each were presented under three conditions differing in the intervals between the six letters within a burst. In the normal condition, each letter was presented for 300 msec and was followed immediately by another letter. In the normal-separated condition, each of the six letters within a burst was followed by a neutral hand position; both the letters and the neutral hand position were held for 300 msec. In the one-letter-per-two-seconds condition, each of the six letters was presented for 300 msec but was followed by a neutral hand position which was held for approximately 1.7 sec.

Figure 1



Experiment 3. Per cent correct report of fingerspelled letters plotted by serial position of the letter within the string. Three rates of presentation are shown.

Each of the 162 bursts of six letters was preceded by a start sign and followed by a finish sign. The intertrial interval was 20 sec for the first two conditions but was extended to 30 sec for the last condition, in order to allow a comparable amount of time for response. The six letters in the fingerspelled bursts were selected randomly with the same constraints as those imposed in Experiment 1. Subjects wrote the letters they saw after each burst was concluded. Subjects were then divided into two groups, depending on whether or not their recall serial position curves were bow-shaped when the letters were separated by neutral signs in the normal-separated condition.

Of the 15 subjects, 6 were naive, while 9 had participated in a previous fingerspelling project. Subjects ranged in age from 20 to 59, with a mean age of about 42. Years of education ranged from 10 to 22, with a mean of 15. The last year of schooling completed ranged from the 7th grade to college.

Results and discussion. At a normal rate of presentation of the fingerspelled items, both groups show essentially monotone decreasing serial position effects, thus replicating the findings of the first experiment, as can be seen in Figure 1. At a slower rate of item presentation, however, clear bow-shaped serial position effects are present in Group 1. At the slowest rate of letter presentation, Group 2 continues to show an essentially monotone declining serial position effect, while Group 1 shows an overall improvement in performance with its serial position curve flattened somewhat.

Table 4

Mean Times (in milliseconds) to Matching Printed Letters for Subjects Differing in their Recall of Fingerspelled Letters

Fingerspelling Recall	Type of Printed Letter Match: Same Case	Mixed Case	Mean	Difference
Bow-shaped (N=8)	770 (s=182.12)	865 (s=239.66)	817.5	95
Monotone (N=7)	675 (s= 67.34)	801 (s= 85.89)	738.0	126
Mean	722.5	833.0		
Difference	95	64		

Note. The extreme mean and standard deviation (s) for the bow-shaped group are influenced by the long response latency of one subject. If that subject's responses are omitted, mean response times for this group are 713 (s=89.00) for the same-case matches, and 790 (s=117.00) for mixed-case matches.

A discriminant analysis based upon this dichotomization indicated that these two groups were statistically different in the way they performed in the letter identification task, F (2,21) = 4.63, p .05. The group showing monotone serial position curves had faster reaction times on physically similar letter matches than Group 1 (see Table 4). However, for the group of subjects showing bow-shaped serial position curves, reaction time for name matches was longer relative to their reaction time on physical matches.

The results of Experiment 3 thus replicate our earlier findings, in pilot studies, of individual differences in the coding of fingerspelled letters and indicate, in addition, a relationship between these individual differences and differences in the processing of pairs of printed letters when they must be matched according to visual or nominal identity. Subjects showing bow-shaped serial position curves for the recognition of letters fingerspelled at a moderate tempo also showed slower reaction times to both physical and name matches of printed letters, as well as a smaller difference between their response times to the two types of matches.

General Discussion

Of primary concern to the present study are the practical implications of our results for construction of guidelines to producing captions that are optimally useful to deaf students. By revealing individual differences in linguistic coding strategies that were consistent across two systems of visual-linguistic symbols, our results indicate that the original experimental question must be redefined, if the goal of constructing maximally useable captions is to be made practicable. The practical implications of the present study, moreover, are supported by a good deal of current literature investigating the processes of letter recognition which may underlie the reading of printed material.

Additionally, our results have meaning in terms of the nature of cognitive processes in deaf people. This series of studies, taken as a whole, yields a pattern of results which lend themselves to interpretation as to the ways in which visually presented linguistic material may be coded and processed in short-term memory by deaf observers. As such, they are of particular relevance to theories about the development and education of deaf children. They are of even wider interest in light of conflicting theories as to the nature of short-term memory and of the letter recognition processes involved in reading.

The results of the present series of studies thus meaningfully contribute to what we know about deaf people in general and to what we know about deaf people when they are viewing captions. In the following discussion, we will start by dealing with the first area of meaning, with what our studies seem to imply generally about short-term memory strategies in deaf people and with the relevance of our studies to letter recognition processes and reading in deaf individuals. Then we will turn to the practical implications of our studies for our initial experimental goal, the construction of guidelines for producing captions that are most useful to audiences of deaf students.

Letter Recognition and Short-term Memory in Deaf People

The simplest model for the recognition of fingerspelled letters would have each letter recognized as it impacts upon the visual system. Once recognized, the letter would then be placed in short-term memory. According to such a model, errors could then arise from two possible sources. They could result from a failure to recognize an item at the time of its presentation; these errors would be evenly distributed across serial position, yielding a curve something like that obtained in Experiment 2. Since in Experiment 2, however, performance is not only stable across serial positions but also rather high, this first source of error would not in itself account for the serial position effects observed in Experiments 1 and 3. Errors could also result from a failure to transfer an item to short-term memory before the succeeding item was presented. With the continued impact upon the visual system of longer strings of letters, these errors might reasonably be hypothesized to increase in frequency, due to the increasing amounts of information the visual system is required to process. If so, the result would be that the further it was within a series, the more likely for any letter to be incorrectly entered into short-term storage. Such errors would result in a monotone decline in performance as a function of serial position; the rate of decrease, however, as contrasted with the absolute per cent correct identification, should be consistent with each additional serial position. Therefore, the difference in slope over the first three serial positions obtained in Experiment 1, when string length was increased, leads us tentatively to reject such a simple model.

Instead, we suggest that a brief visual memory of the occurrence of each letter within a string of letters must first be retained by the viewer before the letter can be recognized. Subsequent identification of each letter is based, in a sequential fashion, upon this short-term visual memory of the fingerspelled letter. We also assume that this short-term visual store has a limited capacity. Because of this limited capacity, the more items presented before identification of a preceding letter has been completed, the less accurately every item in the string can be stored. Identifying these items in order, then, has the consequence that the viewer's report for each item becomes less accurate as the length of the string of letters increases. The error rate for any particular item would also increase the further within the string a letter's serial position was, thus also accounting for a decrease in the slope of the serial position curves as the number of fingerspelled letters the observer must recognize on each trial is increased.

Individual differences in coding strategies. While the nature of the processes underlying these monotone serial position effects remains speculative, the occurrence of these particular curves has implications in its own right. Moreover, any model for fingerspelling recognition must also account for the results obtained with a slower rate of item presentation. While all observers showed similar performance in processing rapidly presented fingerspelled items, they appeared to break into two distinct groups differing in the way in which they retained items delivered at a slower tempo. One group continued to produce essentially

monotone declining functions of serial position, while a second group's serial position curves more closely resembled those normally obtained with auditory short-term memory. These results in themselves begin to suggest a variety of styles in which deaf people acquire and retain cognitive material. This inference is further supported by the fact that the two groups also differed in the sensitivity and magnitudes of their response latencies to two different kinds of matches of printed letters.

Although it must be left to future studies to fully articulate the nature and the stability of individual differences among deaf people in their coding of cognitive material, the present results do suggest a broad distinction among our subjects as to the manner in which they processed the stimuli in the two experimental tasks. Deaf people characterized by monotone serial position curves in the short-term recall of fingerspelled letters may be less efficient in recoding visual information into a linguistic form than deaf people who exhibit bow-shaped serial position effects. At the very least, it can be said that subjects with monotone serial position curves on the fingerspelling task were less efficient in matching printed letters which were of different case but of the same response class, such as A and a, than in matching letters of the same case. In concrete terms, this means that they required an additional 126 msec to identify the same letter of a different case, while deaf people with bow-shaped serial position curves required only an additional 95 msec to accomplish the same task. This would suggest that those subjects with monotone serial position curves, while performing their tasks with considerable skill, varied their coding strategies less efficiently, giving primary emphasis to comparisons of the figural characteristics of the members of each letter pair. Certainly, such an interpretation is consistent with their rapid response to letters of the same case and response class. Unlike the same-case matches, mixed-case letter pairs were not amenable to coding solely on the basis of the physical similarity of the two letters within each pair. Since subjects with bow-shaped serial position curves on the fingerspelling task showed smaller differences in their RT's to the two printed letter-matching tasks, it is suggested that this group of subjects gave primary emphasis to a conceptual coding strategy, perhaps of a verbal or phonemic nature.

The existence of stable individual differences in the coding strategies employed by subjects in letter recognition tasks, although intuitively reasonable, seems only lately to have begun to come under direct experimental investigation. In these few recent studies, there is some support, both direct and indirect, for the interpretation which we have placed upon the results of Experiment 3. Hock, Gordon, & Gold (1975), for example, found that, in matching various types of stimuli, there was consistent among-subject variation of a kind which suggested that some subjects tended to use visual codes, while others relied upon verbal or conceptual codes.

Letter recognition and task demands. Letter recognition processes have become a subject of increasing controversy and concern in the experimental literature of the past few years, their new importance stemming from the current interest in defining the cognitive processes underlying reading.

Yet, in much of the recent literature on letter recognition, individual differences in processing strategies, if mentioned at all, are discussed speculatively as one tentative explanation of why conflicting results might have been obtained across a number of studies. One alternative explanation of disparate findings which seems to have been offered with increasing frequency in recent literature is that subjects change their processing strategies in response to the demands of the experimental task, and that task demands, in turn, vary, sometimes in undefined ways, from study to study. A particularly clear example is given by an experiment in which stimulus conditions were manipulated in order to produce systematic variations in the degree to which subjects relied upon phonetic information in their recognition of words (Hawkins, Reicher, Rogers, & Peterson, 1976). Explanations of disparate experimental results which similarly invoke possible differences in task demands may be found in a number of other recent articles (Estes, 1975; Healy, 1976; Mason, 1975; Mason & Katz, 1976; Smith, Haviland, Reder, Brownell, & Adams, 1976).

It is reasonable to expect that subjects will show flexibility in adapting their processing strategies to the cognitive demands of a particular situation. In our Experiment 3, however, subjects showed individual differences in processing strategies which were consistent across two recognition paradigms varying in both the nature of the stimuli employed and the subjects' tasks. This consistency of individual differences indicates, therefore, that differing task demands cannot fully account for those disparate variations in letter recognition performance of current concern in the literature. Moreover, the fact that the subject differences of interest in the present study were obtained in two separate paradigms argues, in turn, against an interpretation of our results as an artifact of a particular experimental situation.

Interaction of task and individual differences in coding strategies. We would suggest, therefore, that the most useful approach to the study of letter recognition processes, as they relate to reading skill development, requires careful examination of the way in which the demands of a particular reading task may interact with the cognitive approaches characteristic of the particular group of individuals under study. The definition of experimental problems in terms of such attribute-treatment interactions as these is advocated by Cronbach as a fruitful experimental strategy (1957; 1975). A recent example of this kind of approach to the study of letter recognition processes which may underlie reading yielded results which suggest that one important difference between hearing sixth graders reading above and below grade level may be that the poorer readers do not use orthographic information as to the probability of occurrence in English of the letters of the alphabet in each spatial location within words of a given length (Mason, 1975; Mason & Katz, 1976).

Some strategy of this kind may also be an important differentiator of types of deaf readers. Mason's results, however, were obtained with essentially one experimental paradigm, which was itself characterized by some, perhaps minor, methodological problems; the differences which she observed, therefore, must be validated across variations in task demand.

Similarly, the differences among deaf subjects in coding strategy which we have observed, in the present investigation, across two task situations --and two linguistic symbol systems, as well--must be validated and extended to additional cognitive tasks. It would be premature to assume, for example, that subjects would group themselves in terms of their recognition of manual gestures similarly to the way in which they grouped themselves on the fingerspelling and letter recognition tasks.

Cognitive analogy of fingerspelling and printed letters. Fingerspelled and printed letters logically bear a number of similarities which for many deaf observers function to render them two cognitively analogous tasks, more closely related in underlying processes than perhaps to manual gestures. They are, of course, both systems of symbols for the English language which are delivered visually. In contrast to signs, moreover, each symbol tends to represent a subunit of a larger, semantically meaningful, group of symbols, and individual subunits or smaller groupings of these subunits represent orthographic or phonemic elements.

While these logically defined similarities provide something of a theoretical rationale for the obtained relationships between the cognitive processing of letters presented manually or in print, empirical evidence suggests additional bases for these relationships. Results of a number of studies conducted in the past few years indicate that, for many subjects, the individual letter--rather than a semantic or phonemic grouping of letters-- may tend to be the perceptual unit basic to the reading process (Estes, 1975; Mason & Katz, 1976; Massaro, 1975). While these studies employed hearing subjects, their results suggest that, for some deaf people, the fact that both fingerspelling and printed captions are amenable to single-letter processing may be important in evoking similar cognitive strategies for the two linguistic systems. Other studies have indicated that for some reading tasks, the single letters within each word are processed sequentially, rather than in parallel (see, for example, Krueger, 1976; White, 1976). If so, this would yield another basis upon which recognition of fingerspelled and printed captions might be considered congitively analogous; while the sequential manner in which fingerspelled letters are customarily delivered imposes a necessary temporal sequence upon their processing, cognitive functions in some subjects may impose upon the processing of printed letters a temporal distribution similar to that associated with fingerspelled stimuli.

The important point of the results of the present investigation, however, is that whether or not any two modes of linguistic representation are closely related in their processing may well depend upon the cognitive strategies characterizing the individuals at whom they are directed. The implication is that, while for some deaf audiences captions may employ fingerspelled or printed letters with equal effectiveness, for other deaf individuals, one mode of captioning may be clearly contraindicated.

Implications for Captioning

The results of the present study thus have important meaning for the problem of producing captions that will be truly useful to deaf viewers. As noted in the preceding section, moreover, these practical implications

are supported by a good deal of current experimental literature. From the results of the present experiments, therefore, a number of recommendations can be made, both for the captioning of material for deaf audiences and for the further study of optimal captioning techniques.

Implications for the design of studies of captioning. One important facet of any experimental design is the choice of an experimental measure which will show a meaningful degree of sensitivity specific to the variable of interest; technically, this is the problem of selecting a dependent measure which is both reliable and valid. Intuitively, it might seem that subjects' average error rates in identifying the content of a set of captions would yield the most valid measure of the effectiveness of captions varying, for example, in style and locus of [illegible]. In order to be useable dependent measures, however, the mean error rates obtained in any experiment must fall within a range from a minimum value of slightly better than chance performance to a maximum of less than 100%; thus, if subjects perform below chance expectancy or at about 100% correct over the experimental conditions, the information yielded by their error rates is uninterpretable. And, unless the error rates of a randomly sampled group of subjects are reasonably uniform within each experimental condition, then interpretation of variations in the average performance of that group runs a heavy risk of invalidity.

Yet, the results of our studies with two simple cognitive tasks--the identification of fingerspelled letters and matching of printed letters--indicate that it is unlikely that the error rates of individuals in identifying caption content would be uniform enough to make the average data of a randomly sampled group of deaf subjects meaningful. This is because there seems to be an important source of within-group variation among deaf subjects in their processing of linguistic information. If, for example, reaction times in Experiment 3 to the letter matching task had been averaged across all subjects, regardless of their serial position curves on the fingerspelling task, the resultant mean score would have masked important differences in performance between the two groups of subjects, and interpretation of this distortion of the true state of affairs would have been invalid and misleading. Any standards for caption presentation based upon this overall mean would have been suitable for neither group of cognitive processers.

Thus, an important finding of the present series of studies is that any random sample of deaf subjects will likely be nonhomogeneous with respect to their individual modes of processing the linguistic stimuli presented in simple cognitive tasks. If mean performance is then obtained and analyzed across such a nonhomogeneous group, then an unacceptable proportion of the data submitted to analysis and subsequent interpretation will be due to an uncontrolled and misleading source of variation (Namboodiri, Carter, & Blalock, 1975).

One possible way in which such between-subject variation might be removed would be statistical control. Thus, a common measure of cognitive processing might be obtained for each subject and entered, either as a covariate or as an additional predictor, into an analysis of their

performance under the different experimental conditions. Ideally, this approach would render more interpretable that variation in performance which was truly due to caption differences. It is difficult to say, however, exactly what measure could be employed for this purpose. It would seem that finding such a measure would greatly advance the replicability and interpretability--the validity, in short--of the results of studies of the performance of deaf subjects on many linguistic tasks, including the reading of printed captions. At present, however, our data indicate primarily that interpretation of the results of such studies must be tempered by awareness that there are pronounced, but, as yet, little understood, differences among deaf people in their performance on simple cognitive tasks.

Implications for the captioning of material for deaf students. The major outcome of our findings is to open up the possibility that there is no one optimal means of captioning material for deaf students. Indeed, one mode of captioning--printed literal captions--may be desirable for individuals who emphasize one cognitive mode, while captioning with manual communication may be preferable for students whose dominant processing style differs from that of the first group.

Our results point, however, to the direction which efforts at tailoring captions to meet the needs of particular audiences of deaf students might take. We have found evidence that there are consistent differences among deaf people in their styles of processing cognitive material. None of the intuitively more obvious details of the personal histories of our subjects --age at onset of deafness, degree or type of education, for example--seemed to account for these differences. It would appear, moreover, that these differences in their cognitive modes will be important determinants of the utility of each means of captioning to any specific target group of deaf students; to ignore these individual differences when designing captioned material may be to achieve a compromise which is useful to neither group of individuals.

The task for research, therefore, is to further define the nature of these individual differences and to find valid and easily administered measures of them. And the question fundamental to deriving standards for the production of captions that are truly useful to deaf viewers then becomes that of identifying--according to these differences--the group of deaf people for whom a set of captions is intended.

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